Renewable and Sustainable Energy Reviews 15 (2011) 745–751

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

# Economic assessment of biodiesel production: Comparison of alkali and biocatalyst processes

Kenthorai Raman Jegannathan [a], Chan Eng-Seng [b], Pogaku Ravindra [b,*]

[a] Department of Biotechnology, School of Biotechnology and Health sciences, Karunya University, Coimbatore, 641114, India
[b] Centre of Materials and Minerals, School of Engineering and Information Technology, University Malaysia Sabah, 88999 Kotakinabalu, Sabah, Malaysia

ARTICLE INFO

*Article history:*
Received 11 December 2009
Accepted 20 July 2010

*Keywords:*
Biodiesel
Economic assessment
Alkali catalyst
Soluble lipase
Immobilized lipase
Production cost

ABSTRACT

This study deals with the economic assessment of biodiesel production using three catalytic processes (1) alkali (2) soluble enzyme and (3) immobilized enzyme. All the processes were considered to be operated at batch mode with a production capacity of $10^3$ tonne. Biodiesel production cost using alkali catalyst process was found to be lowest ($ 1166.67/tonne) compared to soluble lipase catalyst ($7821.37/tonne) and immobilized lipase catalyst ($2414.63/tonne) process. The higher production cost was due to the higher cost of the enzyme and the higher reaction time of enzymatic process. However, reuse of immobilized catalyst decreased the production cost drastically unlike soluble enzyme catalyst.


**Contents**



## 1. Introduction

Majority of human energy needs are currently met using petrochemical sources, coal and natural gases. As the demand for energy has grown, so have the adverse environmental effects of its production. Biodiesel may offer an excellent alternative to the fossil fuels, representing a cornerstone to steer our energy system in the direction of sustainability and supply security. Therefore, biodiesel has become a high priority in the energy policy strategies at national level as well as at a global scale. Further, biodiesel production and use has become mandatory nowadays due to its environmental benign characters. The production of biodiesel is increasing and the current global production is approximately $12 \times 10^6$ tonne. In addition, the biodiesel production capacity increased $26 \times 10^6$ tonne in 2008 compared to $10.5 \times 10^6$ tonne 2007 [1]. These figures are likely to increase further, due to the implementation of 20% blend of biofuels in conventional diesel fuel in many countries. In addition, the recent biofuel policy 20:20:20 passed by the European Union will lead to drastic increase in biodiesel production in the world scenario [2].

Transesterification of triglycerides with alcohol in the presence of chemical catalyst, biocatalyst or non-catalyst leads the

* Corresponding author at: Department of Chemical Engineering, School of Engineering and Information Technology, University Malaysia Sabah, Kotakinabalu 88999, Malaysia. Tel.: +60 88 320533; fax: +60 88 320539.
*E-mail address:* dr_ravindra@hotmail.com (P. Ravindra).

1364-0321/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.rser.2010.07.055

formation of alkyl ester commercially known as biodiesel. The current technology in industries uses chemical catalyst for biodiesel production, which may lead to pollution problems due to the soap formation in the transesterification process. For this reason, enzymatic transesterification using lipase looks attractive and encouraging in biodiesel production leading to minimal wastewater treatments needs, easy glycerol recovery and absence of side reactions [3]. Practical use of lipase in pseudo homogenous reaction systems presents several technical difficulties such as contamination of the product with residual enzymatic activity and economic cost [4]. In order to overcome this problem, the enzyme is usually used in immobilized form so that it can be reused several times to reduce the cost, and also to improve the quality of the product. A rigorous research is being conducted all over the world to implement enzymatic biodiesel production in large scale.

Economic assessment is a key driving force supporting the development of process technology. Economical assessment can be used to predict the cost of the process plant, product manufacturing cost, compare the cost of product produced via different processes and conditions [5]. Economic studies on biodiesel using various chemical catalytic processes were reported previously [5–9].

In general, biodiesel production using biocatalyst process is considered to be costly compared to the alkali catalyst process. But there is no economic study reporting the cost of biodiesel production using biological catalyst. Comparison of economic assessment of biodiesel production using alkali and biocatalyst could lead to the insight of the cost range involved, leading to develop biocatalyst process towards cheaper production cost. Therefore, in this work an attempt is made to study the economic assessment of biodiesel production using alkali catalyst and biological catalyst.

## 2. Methods

The biodiesel manufacturing, equipment and plant cost involved were estimated for a production capacity of 1000 tonne. Variable costs were calculated on the basis of the quantities and the unit prices of raw materials, products, and utilities; fixed costs were calculated on the basis of plant cost and employee cost [9]. The procedure for estimating the production costs for a 1000 tonne capacity is as follows:

- Development of process flow sheets
- Development of process time charts
- Development of equipment lists
- Estimation of equipment cost
- Estimation of the plant cost
- Estimation of manufacturing cost

### 2.1. Process flow sheets

Biodiesel production was carried out in a stirred tank reactor with batch mode of operation. After transesterification, the biodiesel and the glycerin were formed on settling. The upper layer of biodiesel is washed using hot water and distilled to obtain purified biodiesel.

In case of alkali chemical catalyst, the byproduct glycerin was passed to the neutralization tank and the water in the glycerin is separated using distillation process. The crude glycerin is sent to crystallizer, to separate the soap formed in the transesterification reaction Fig. 1. The crystallization step is avoided (Figs. 2 and 3) in the biocatalyst processes due to the absence of soap formation.

### 2.2. Process time charts

Process time charts for the three processes are shown in Figs. 4–6. The batch cycle time of alkali catalyst process was 16 h, whereas, the batch cycle time of both biocatalyst processes were 83 h. To equalize the batch reaction time and the production capacity of all the three process, it was assumed that five transesterification units in biocatalyst processes were operated simultaneously, compared to single transesterification unit using alkali catalyst process. Hence, the cost for five transesterification units was calculated in biological catalyst processes.

### 2.3. Equipment list

The specifications of the equipments in a raw material and product yard, main process yard, and utility yard for a biodiesel production capacity of 1000 tonne are shown in Table 1.

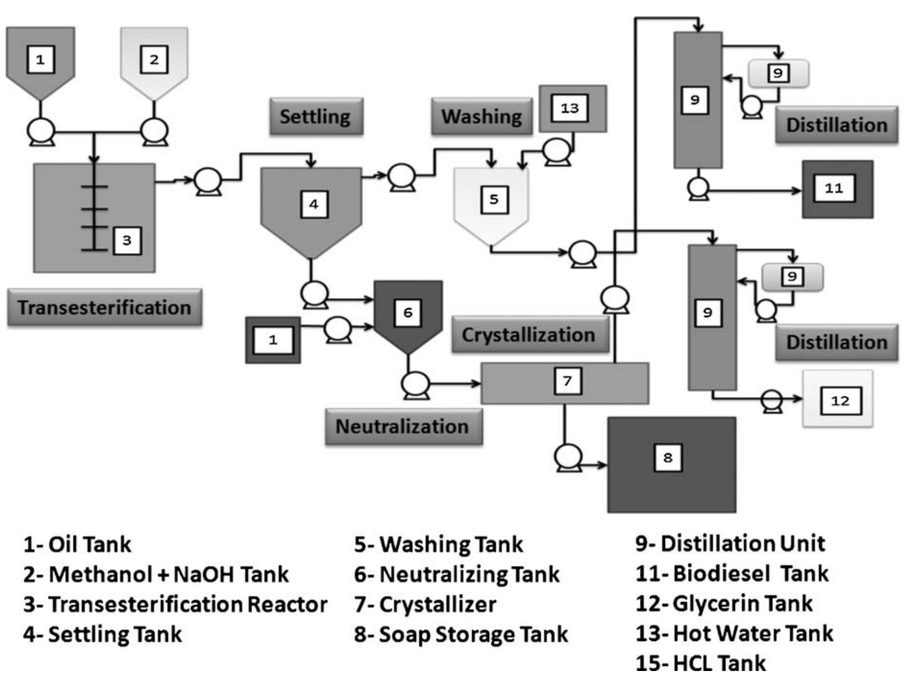


**Fig. 1.** Sketch of biodiesel production plant using alkali catalsyt.

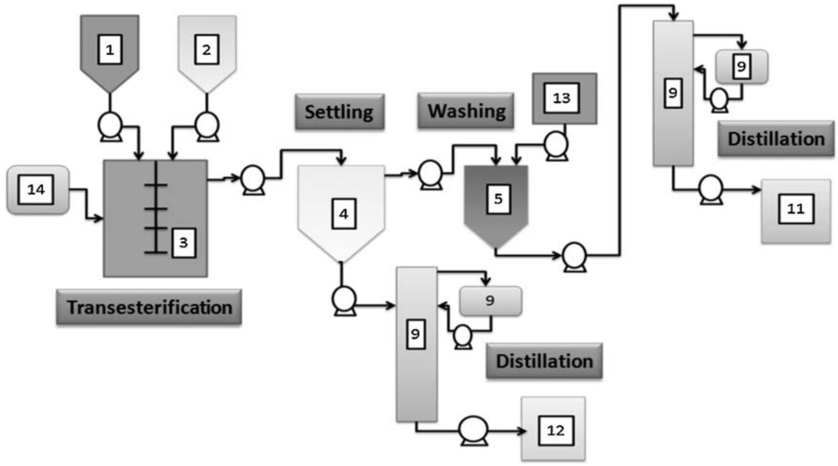


**Fig. 2.** Sketch of biodiesel production plant using soluble lipase catalsyt.

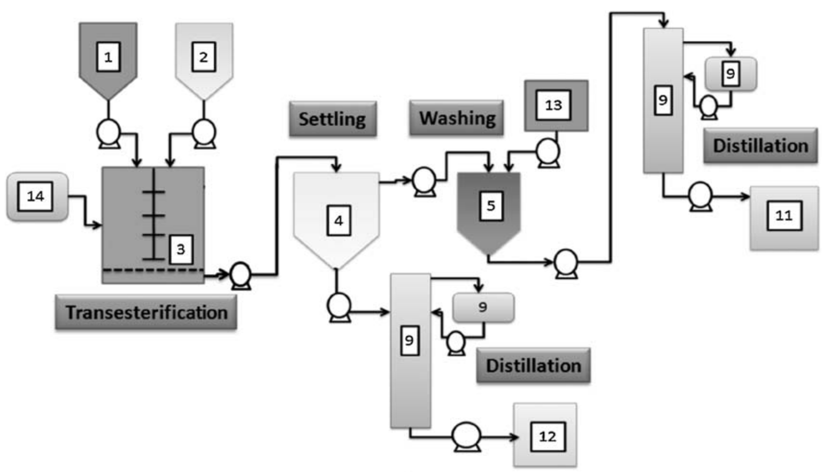


**Fig. 3.** Sketch of biodiesel production plant using immobilized lipase catalsyt.

## 3. Cost estimation

The procurement costs or fabrication costs of the equipment for 1000 tonne of biodiesel are shown in Table 1. The costs involved in the main process and utility yard for the alkali catalyst ($ 633,871) were lower than those for the soluble enzyme catalyst ($ 992,327) and immobilized enzyme catalyst processes ($ 996,327).

### 3.1. Plant cost

The different catalyst processes, total plant investment costs are shown in Table 2. The total plant cost was determined to be 333% for a total equipment cost of 100% on the basis of the factors responsible for the commercial biodiesel batch plant. Consequently, the total plant costs for the alkali, soluble and immobilized catalyst processes were $2.10 million, $3.30 million and $3.31 million, respectively (Fig. 7). From the figures it can observed that, the plant cost for biodiesel production using immobilized enzyme was 57.18% higher than the alkali catalyst process and 0.40% higher than soluble enzyme catalyst process. The high cost for both the soluble and immobilized catalyst process was due to the process time variation with respect to the alkali catalyst. To achieve the process time equal to the alkali chemical catalyst, the enzymatic catalyst process was calculated to operate 5 units. Hence the plant cost for the enzymatic process has increased drastically compared to the alkali chemical catalyst biodiesel production process. Likewise, a marginal increase of plant cost for immobilized catalyst process over soluble enzyme process was due to the addition of encapsulation unit, which has caused a 0.4% increase.

### 3.2. Manufacturing cost

The manufacturing costs for the biodiesel production using alkali process [10], soluble and immobilized lipase [11,12] processes for 1 tonne capacity plant are estimated, as shown in Table 3. The unit prices of the palm oil, methanol, water, sodium hydroxide, HCl, lipase, κ-carrageenan and KCl used as raw materials are fixed at ($) 0.56/Kg, 0.45/kg, 2.27/tonne, 1.82/kg, 2/kg, 150/kg, 10/kg, and 1.8/kg respectively. The unit prices of the heating energy and electric power are fixed at $0.0227/MJ and

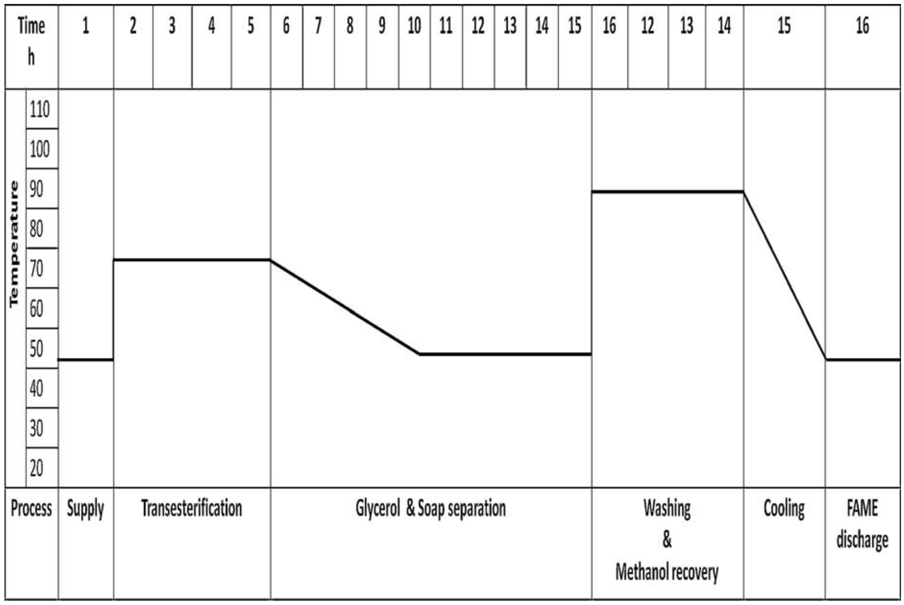


**Fig. 4.** Process time chart for biodiesel production using alkali catalyst.

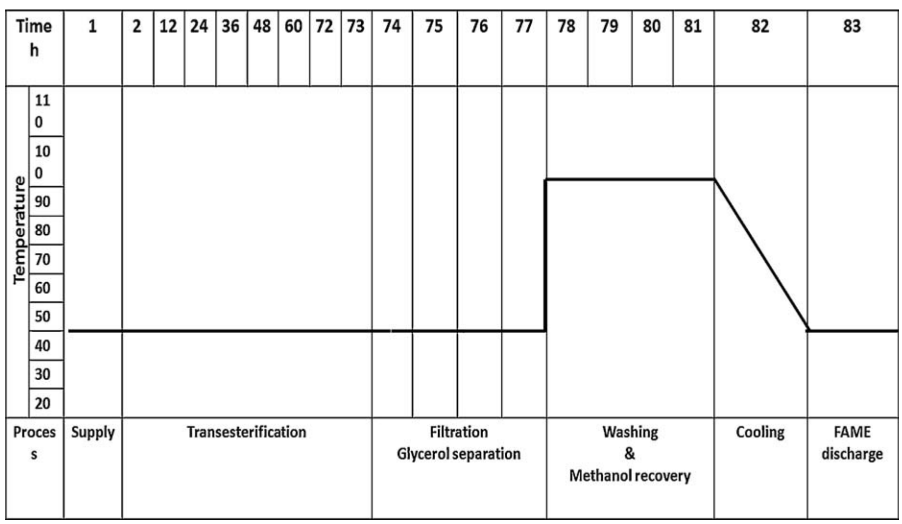


**Fig. 5.** Process time chart for the biodiesel production using soluble enzyme catalyst.

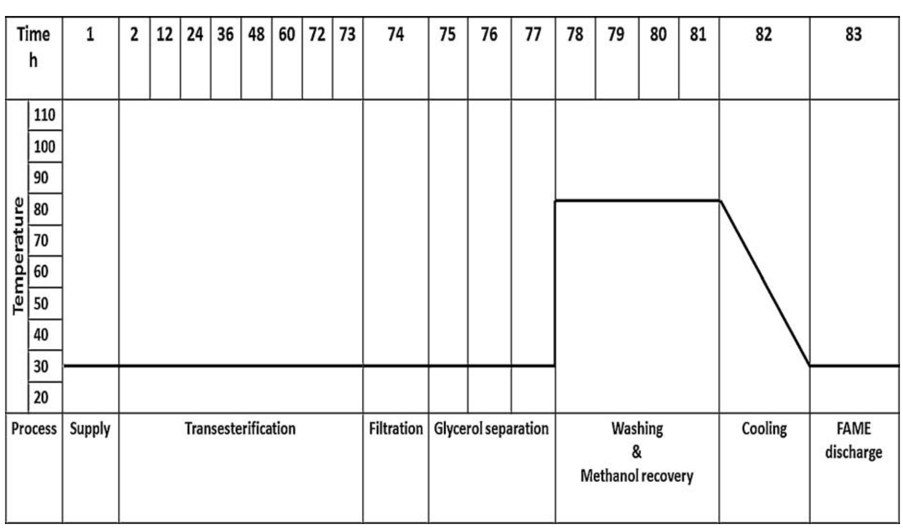


**Fig. 6.** Process time chart for the biodiesel production using immobilized enzyme catalyst.

**Table 1**
Equipment specifications and procurement costs for biodiesel production of 1000 tonne capacity with different catalytic processes.

| Service specification | Capacity | Price $ | | |
|---|---|---|---|---|
| | | Alkali catalyst process | Soluble enzyme catalyst | Immobilized enzyme catalyst |
| Palm oil tank | 30 kl | 27,272 | 27,272 | 27,272 |
| Methanol tank | 10 kl | 27,273 | 27,273 | 27,273 |
| Hot water tank | 10 kl | 12,121 | 12,121 | 12,121 |
| FAME tank | 6 kl | 27,272 | 27,272 | 27,272 |
| Glycerol tank | 2 kl | 4000 | 4000 | 4000 |
| Waste water tank | 2 kl | 4000 | 4000 | 4000 |
| Oil pump | 10 kl/h | 3636 | 3636 | 3636 |
| Fresh methanol pump | 3 kl/h | 2727 | 2727 | 2727 |
| Hot water pump | 3 kl/h | 2727 | 2727 | 2727 |
| FAME pump | 15 kl/h | 3636 | 3636 | 3636 |
| Waste glycerol pump | 10 kl/h | 3182 | 3182 | 3182 |
| Waste water pump | 10 kl/h | 3182 | 3182 | 3182 |
| NaOH storage unit | 2 kl | 4000 | | |
| HCl storage unit | 2 kl | 4000 | | |
| Lipase storage unit | 2 kl | | 4000 | 4000 |
| Encapsulation unit | | | | 4000 |
| Raw material & product yard total | | 129,028 | 125,028 | 129,028 |
| Transesterification vessel | 6 kl | 100,364 | 501,820 | 501,820 |
| Methanol vessel | 1 kl | 11,727 | 11,727 | 11,727 |
| Waste water vessel | 0.2 kl | 2045 | 2045 | 2045 |
| FAME vessel | 4 kl | 5618 | 5618 | 5618 |
| Glycerol vessel | 0.5 kl | 6045 | 3045 | 3045 |
| Waste water vessel | 0.5 kl | 6045 | 3045 | 3045 |
| FAME heater | 10 $m^2$ | 27,273 | 27,273 | 27,273 |
| Vessel condenser | 10 $m^2$ | 27,273 | 27,273 | 27,273 |
| Vessel after cooler | 5 $m^2$ | 8182 | 8182 | 8182 |
| FAME filter(1) | 5 $m^2$ | 9091 | 9091 | 9091 |
| FAME filter(2) | 5 $m^2$ | 9,091 | 9091 | 9091 |
| FAME pump | 10 kl/h | 3182 | 3182 | 3182 |
| Methanol pump | 3 kl/h | 2727 | 2727 | 2727 |
| FAME pump | 10 kl/h | 3182 | 3182 | 3182 |
| Waste glycerol pump | 3 kl/h | 2727 | 2727 | 2727 |
| Waste water pump | 3 kl/h | 2727 | 2727 | 2727 |
| Main process yard total | | 227,299 | 622,755 | 622,755 |
| Cooling tower | 540,000 kJ/h | 20,636 | 13,636 | 13,636 |
| Cooling water tank | 5 kl | 9091 | 9091 | 9091 |
| Cooling water pump | 40 kl/h | 2727 | 2727 | 2727 |
| Cooling water pump | 40 kl/h | 2727 | 2727 | 2727 |
| Chilling unit | 69,000 kJ/h | 27,273 | 27,273 | 27,273 |
| Chilling water tank | 1 kl | 4545 | 4545 | 4545 |
| Chilling water pump | 3 kl/h | 2727 | 2727 | 2727 |
| Chilling water pump | 3 kl/h | 2727 | 2727 | 2727 |
| Steam boiler unit | 500 kg/h | 45,455 | 45,455 | 45,455 |
| Hot oil heater unit | 800 MJ/h | 72,727 | 72,727 | 72,727 |
| Vacuum pump unit | 51 kl/h | 9091 | 9091 | 9091 |
| Air compressor unit | 75 N $m^3$/h | 18,182 | 18,182 | 18,182 |
| Nitrogen generator unit | 15 N $m^3$/h | 63,636 | 33,636 | 33,636 |
| Utility yard total | | 281,544 | 244,544 | 244,544 |
| Plant cost | | 633,871 | 992,327 | 996,327 |

**Table 2**
Total plant investment costs for biodiesel production with a capacity of 1000 tonne using different catalytic processes.

| Equipment | 100 (%) | 633,871 | 992,327 | 996,327 |
|---|---|---|---|---|
| Installation | 10 | 63387.1 | 99232.7 | 99632.7 |
| Piping | 30 | 190161.3 | 297698.1 | 298898.1 |
| Insulation and painting | 5 | 31693.55 | 49616.35 | 49816.35 |
| Civil and structure | 70 | 443709.7 | 694628.9 | 697428.9 |
| Electric and instrumentation | 35 | 221854.9 | 347314.5 | 348714.5 |
| Computer system | 25 | 158467.8 | 248081.8 | 249081.8 |
| Engineering and supervising | 36 | 228193.6 | 357237.7 | 358677.7 |
| General | 22 | 139451.6 | 218311.9 | 219191.9 |
| Plant cost | 333% | 2,110,790 | 3,304,449 | 3,317,769 |

**Table 3**
Manufacturing costs for biodiesel production.

| Expenses | Price ($) | Alkali catalyst | | Soluble enzyme catalyst | | Immobilized enzyme catalyst | |
|---|---|---|---|---|---|---|---|
| | | Quantity | Cost | Quantity | Cost | Quantity | Cost |
| Raw material | | | | | | | |
| Palm oil | 0.56/kg | 995 | 557.2 | 995 | 557.2 | 1050 | 588 |
| Methanol | 0.45/Kg | 263 | 118.35 | 263 | 118.35 | 263 | 118.35 |
| Tap water | 2.27/tonne | 147 | 2.27 | 130 | 2.27 | 130 | 2.27 |
| Sodium hydroxide | 1.82/kg | 10 | 18.2 | | | | |
| HCl | 2/kg | 38 | 76 | | | | |
| Lipase | 150/kg | | | 40 | 6000 | 8 | 1200 |
| κ-Carrageenan | 10/kg | | | | | 10 | 60 |
| KCl | 1.8/kg | | | | | 3 | 5.4 |
| Utilities | | | | | | | |
| Steam | 0.0227/kg | 1820 | 41.314 | 1000 | 22.7 | 1100 | 24.97 |
| Electricity | 0.136/kW h | 8.6 | 1.1696 | 5 | 0.68 | 5 | 0.68 |
| Manpower | | 8 | 300 | 8 | 300 | 8 | 300 |
| Total | | | 1114.50 | | 7001.2 | | 2299.67 |
| Byproducts | | | | | | | |
| Glycerol | 2/kg | 50 | 100 | 100 | 200 | 100 | 200 |
| Total | 100% | | 1014.50 | | 6801.2 | | 2099.67 |
| Depreciation | 9% | | 91.30 | | 612.10 | | 188.93 |
| Repair | 3% | | 30.43 | | 204.03 | | 62.99 |
| Interest and tax | 3% | | 30.43 | | 204.03 | | 62.99 |
| Total | | | 1166.67 | | 7821.37 | | 2414.63 |

**Table 4**
Comparative economic assessment between previous and present studies for biodiesel production plants.

| Plant capacity (tonne/year) | Process type | Catalyst | Oil feed stock | Feedstock cost \$/tonne[a] | Glycerol credit \$/tonne[a] | Manufacturing cost \$/tonne[a] | Plant cost \$million | Reference |
|---|---|---|---|---|---|---|---|---|
| 8000 | Continuous | Homogenous alkali | Soybean oil | 779 | 380 | 685 | 1.35 | [5] |
| 8000 | Continuous | Homogenous alkali | Soybean oil | 208 | 73 | 526 | 11.67 | [7] |
| 36,036 | Continuous | Homogenous alkali | Waste cooking oil | 445[b] | 74 | 423 | 7.42[c] | [8] |
| 7260 | Batch | Homogenous alkali | Waste cooking oil | 248 | 0 | 641 | 7.9[c] | [9] |
| 1000 | Batch | Homogenous alkali | Palm oil | 557 | 100 | 1167 | 2.11[c] | This work |

[a] Based on tonne-FAME.
[b] Raw material cost.
[c] Includes utility equipment.

\$0.136/kW h, respectively. The annual costs of depreciation and repair are estimated at 9% and 3% of the plant investment cost. The annual cost of interest and tax are estimated at 3% of the plant cost.

The manufacturing cost (per tonne) of immobilized enzyme catalyst process was 206.96% higher than alkali catalyst process and 323.9% lesser than the soluble enzyme catalyst process (Fig. 8). The higher price of lipase attributed to the higher price of biodiesel using homogenous biocatalyst process compared to the alkali catalyst. But, the price of biodiesel using heterogeneous biocatalyst process was comparatively very less than homogenous catalyst due to its reusable capability.

## 4. Comparison between previous study and present study

These is no literature available on the economic assessment of biodiesel using biological catalyst, hence comparison is not possible. However, in the economic assessment of biodiesel using alkali catalyst (Table 4) Sakai et al. [9] reported a manufacturing

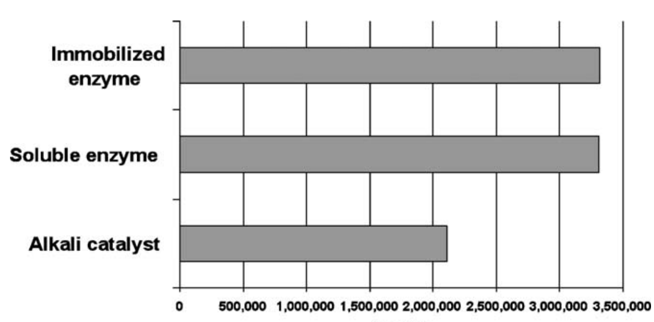


**Fig. 7.** Plant investment costs for 1000 tonne capacity biodiesel production.

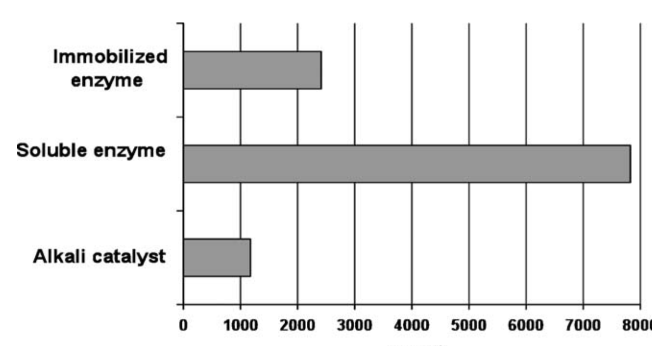


**Fig. 8.** Manufacturing costs for 1 tonne capacity biodiesel production.

cost of 641 $/tonne and plant cost 7.99 $million/7260 tonne for biodiesel production from waste cooking oil using KOH catalyst batch process, Marchetti and Errazu [8] has reported manufacturing cost of 429 $/tonne and plant cost 7.42 $million/36,036 tonne for biodiesel production from waste cooking oil using alkali catalyst continuous process, You et al. [5] has reported manufacturing cost of 779 $/tonne and plant cost 1.35 $million/8000 tonne for biodiesel production from soybean oil using alkali catalyst continuous process. In the present study, the manufacturing cost was found to be 1167 $/tonne and plant cost 2.12 $million/1000 tonne for biodiesel production from palm oil using alkali catalyst batch process. The high price for palm oil and manpower are the factors for the biodiesel cost to be high compared to the previous reported studies.

## 5. Conclusion

The objective of this study was to find the price range of biodiesel production using enzymatic catalyst process cost compared to the alkali catalyst studies conducted elsewhere. In this study, the economical assessment of biodiesel production using three different (i) alkali catalyst, (ii) Soluble biocatalyst and (iii) immobilized biocatalyst was examined. Biodiesel production cost using alkali catalyst was found to be lower compared to the other two processes. The manufacturing cost (per tonne) of immobilized enzyme catalyst process was 206.96% higher than alkali catalyst process and 323.9% lesser than the soluble enzyme catalyst process indicating that the reusability of the immobilized lipase enzyme play a major role in reduction of biodiesel production in biocatalyst process. In this study, the immobilized lipase was assumed to be reused for 5 times only. If the reuse capabilities of the immobilized lipase could be enhanced, it can compete with cost of the alkali catalyst process. In addition, the cost of lipase also plays a major role. With the development of white biotechnology in the forefront, the cost of lipase is expected to be lower in the near future.

## References

[1] Licht FO. World ethanol & biofuels. Report no. 16; 2008.
[2] MPOC. Malaysian palm oil council annual report; 2008.
[3] Ravindra P. Biofuels scenario in Asian Countries. In: Proceedings of 2006 world congress on industrial biotechnology and bioprocessing; 2006.
[4] Al-zuhair S. Production of biodiesel: possibilities and challenges. Biofeedback Bioprod Bioref 2007;1:57–66.
[5] You YD, Shie JL, Chang CY, Huang SH, Pai CY, Yu YH, et al. Economic cost analysis of biodiesel production: case in soybean oil. Energy Fuels 2008;22:182–9.
[6] Van Kasteren JMN, Nisworo AP. A process model to estimate the cost of industrial scale biodiesel production from waste cooking oil by supercritical transesterification. Resour Conserv Recyc 2007;50:442–58.
[7] West AH, Posarac D, Ellis N. Assessment of four biodiesel production processes using HYSYS plant. Bioresour Technol 2008;99:6587–601.
[8] Marchetti JM, Errazu AF. Technoeconomic study of supercritical biodiesel production plant. Energy Convers Manage 2008;49:2160–4.
[9] Sakai T, Kawashima A, Koshikawa T. Economic assessment of batch biodiesel production processes using homogeneous and heterogeneous alkali catalysts. Bioresour Technol 2009;100:3268–76.
[10] Lin CY, Chiu CC. Effects of oxidation during long-term storage on the fuel properties of palm oil-based biodiesel. Energy Fuels 2009;23:3285–9.
[11] Jegannathan KR, Chan ES, Ravindra P. Physical and stability characteristics of *Burkholderia cepacia* lipase encapsulated in κ-carrageenan. J Mol Cat B Enzyme 2009;58:78–83.
[12] Jegannathan KR, Leong JY, Chan ES, Ravindra P. Designing an immobilized lipase enzyme for biodiesel production. J Renew Sust energy 2010;1:063101.